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ASD INTERIM REPORT 8-III (I)
OCTOBER 1963

ELECTRO-SPARK EXTRUDING

G. PFANNER
J.H. WAGNER

REPUBLIC AVIATION CORPORATION
MANUFACTURING RESEARCH

CONTRACT: AF 33(657)11265 new
ASD PROJECT: 8-III

INTERIM PROGRESS REPORT
1 JULY 1963 to 1 OCTOBER 1963

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

AERONAUTICAL SYSTEMS DIVISION
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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October, 1963

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(10) by G. Pfanner and
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(5) Republic Aviation Corp[redacted] Farmingdale, N. J.

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Republic Aviation Corporation Report No. RAC 1776

Pressure chamber design requirements are stated as well as a presentation of dynamic stress considerations.

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY
Aeronautical Systems Division (AFSC)
United States Air Force
Wright-Patterson Air Force Base, Ohio

ABSTRACT-SUMMARY
Interim Technical
Progress Report No. 1

ASD INTERIM REPORT 8-111 (I)
October 1963

ELECTRO-SPARK EXTRUDING

G. Pfanner
J.H. Wagner

Republic Aviation Corporation

The results of a literature survey are outlined. The pressure vessel design requirements are stated. Dynamic stress considerations in pressure vessel design are discussed.

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FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF33(657)11265 from July 1, 1963 to September 30, 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This contract with Republic Aviation Corporation of Farmingdale, New York, was initiated under ASD Manufacturing Technology Laboratory Project 8-111, "Electro Spark Extruding." It is administered under the direction of Mr. T. Felker of the Basic Industry Branch ASRCTB, Manufacturing Technology Laboratory, Aeronautical Systems Division, Wright Patterson Air Force Base, Ohio. Mr. J.H. Wagner is the engineer in charge of the project. Contributing to the program is Mr. Gunther Pfanner, Pr. Mfg. Rsch. Group Engr. Dynamic stress considerations are being investigated by Dr. I. Ojalvo and Mr. B. Leftheris of the Advanced Research and Development Facility of Republic Aviation Corporation.

The primary objective of the Air Force Manufacturing Methods Program is to increase producibility, and to improve the quality and efficiency of fabrication of aircraft, missiles and components thereof. This report is being disseminated in order that methods and/or equipment developed may be used throughout industry, thereby reducing costs and giving "MORE AIR FORCE PER DOLLAR."

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional manufacturing methods development required on this or other subjects will be appreciated.

Written by: J.H. Wagner
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INTRODUCTION

The acceleration of technological development has made available to the manufacturing engineer knowledge relating to diverse phenomena that are often suited to metal fabrication processes. One more recent advance is the successful application of the high power release of stored electrical energy for sheet metal forming operations. Having attained successful accomplishments in this area, a natural exploitation of this development is the application of capacitor discharge phenomena to other metal fabrication procedures.

Capacitor discharge extrusion is a metal fabrication process that utilizes the high power of rapid discharge of electrical energy stored in capacitors. One method of accomplishing extrusion is to use the energy derived from the pressure pulse directly on the billet. This objective may be attained in an appropriate container by repetitive discharges between electrodes in a liquid filled container under hydrostatic pressure. The hydrostatic pressure is intended to increase the efficiency and power derived from the stored electrical energy. Such increase is expected due to the greater constraint of the discharge by the pressure environment and since elastic work loss upon the billet per discharge is reduced. The capacitor discharge impulses are intended to produce pulse pressures considerably in excess of pressures attainable hydrostatically or mechanically in tooling of comparable size. It is believed that the short duration of the pulse pressures will permit the superposition of pressure without corresponding increase in the design strength of the container by hydrostatic standards.

A second method of capacitor discharge extrusion that can be used is to recover the energy derived from the discharge explosion and transfer it by mechanical means to the billet. This goal can be attained either by using a series of capacitor discharges as a means of pumping to a higher pressure and using the resultant pressure on a piston of large area relative to the billet area in order to extrude in a manner similar to extrusion with a conventional press; or to use the pressure pulse energy created by spark discharge directly on the face of the large area piston and to move the piston-ram toward billet reduction by means of a series of discharges impinging on the face of the piston.

The apparent advantages offered in the first case are those attributed to hydrostatic extrusion, i.e., (1) elimination of billet-container wall friction and (2) reduction of billet die surface friction. Additionally, with peak pulse pressures considerably greater than hydrostatically obtainable, extrusion capability, in terms of material resistance or extrusion ratio, is increased. The second method has the feature of accomplishing extrusion with lower pressures,thereby; (1) reducing container size and cost, (2) substantially reducing the problem of electrode sealing, (3) creating a versatile piece of equipment adaptable to several approaches for extrusion.

Recognizing the attractive advantages offered by the application of this technology, the Aeronautical Systems Division of Wright Patterson Air Force Base, has awarded Contract No. AF33(657)11265 to Republic Aviation Corporation to determine the production potential for extruding steel alloys by capacitor discharge energy. This will be accomplished in the course of the program by conducting experiments with capacitor discharge equipment to develop the most suitable techniques for extruding steel sections. The program consists of two phases as follows:

Phase I - Design and Construction of the Equipment
Phase II - Development of the Extruding Process

Both of the methods heretofore described will be investigated for suitability to realize the objective of the program of extruding of a 2 inch diameter billet to 1/4 inch rounds.

It appears desirable to design a versatile pressure vessel and hydraulic cylinder adaptor to permit experiments with and without the adaptor to determine which method has the greatest potential for developing the capacitor discharge extrusion process. Basic operating conditions will be modified in order that steel extrusions to cited specifications can be produced. As the objective of the program is to determine the production potential of the method, no physical properties nor metallurgical data associated with the extruded produce will be recorded.

This is the first interim report and covers the work from July 1, 1963 to October 1, 1963.

LITERATURE SURVEY

A literature search in the field of capacitor discharge extrusion reveals very little data reported. Several articles relating to the generation of pressure by capacitor discharge techniques and the utilization of a capacitor discharge in a hydrostatic environment to lower pressure requirements for extrusion, have appeared in Russian Technical literature. The articles present information of small relative value to this program but are listed in the following in synopsis form with a brief comment as to their significance.

"EXTRUSION.... WITHOUT PLUNGERS" (1958) - P. Ospelov, V. (1) Promyshlenno Ekonomicheskaya Gazeta, Aug. 10, 1958, pp 4

This article cites the advantages that are associated with the High Pressure Extrusion Process. Friction in the contact zones of the container walls, billet, and die are greatly reduced resulting from the formation of a thin fluid film (Hydrodynamic Wedge). This reduction in friction at high pressures results in, (1) lower forces necessary to initiate extrusion and, (2) unusual strength and plasticity of the extruded specimen. The hydrostatic extrusion pressure was found to be 4,500 atmospheres (67,500 psi). Several experiments were conducted with a preheated billet and container which further lowered the initial resistance to deformation.

From these hydraulic extrusion experiments, the investigators came to the conclusion that extrusion is possible without high-pressure compressors. In this case only a relatively low (several hundred atmospheres) hydrostatic pressure is generated in the extrusion container. The extrusion process begins with the aid of a shock wave generated within the container by a powerful electrical discharge.

"A METHOD OF OBTAINING HIGH AND SUPERHIGH PRESSURES" (1960) - Yutkin, L.A., Gol'tsova, L.I. (2) - Byulleten'izobretniy, 1960, No. 13, pp 76

An application of the Electrohydraulic spark gap method which uses pipe, wire or strap for the spark initiation. The various initiation elements employed are shaped to form conical or spherical spirals and are coupled

to flat or curved deflectors for a maximum degree of energy focusing. This technique permits boosting the intensity of repeated capacitor discharges to obtain high and superhigh pressures. The aforementioned techniques are cited as improvements applicable to a device cited in an earlier article by the same authors entitled "A Method of Obtaining Super-High Hydraulic Pressures and a Device for this Purpose" dated 1960. This article briefly describes a high energy electrohydraulic multichamber device. Each chamber contains discharge electrodes that generate a pulsating pressure by repeated time-controlled discharges. The chambers are designed in the form of Parabolas placed one inside another so as to direct the reflected energy towards a receiver. The sequential discharges are time controlled such that the reflected shock wave is reinforced in a step-wise manner to achieve pressures of very high magnitude. The use of curved reflectors for focusing energy is not new, but certainly deserves consideration as a potential tool.

"A HYDRAULIC VOLUMETRIC PUMP" (1959)
Yutkin, L.A., Gol'tsova, L.I. (3)
Byulleten'izobreteniy, 1958, Nr 2, pp 104

The above mentioned techniques are utilized - namely, the use of electrodes within a single hemispherical chamber to generate and direct a pulsating pressure by repeated discharges. The use of electrohydraulic discharges to displaced or pump fluids is feasible, however, no details regarding the pump's construction or capacity was given.

"A HYDRAULIC CAPACITY PUMP" (1959)
Yutkin, L.A., Gol'sova, L.I. (4)
Byulleten'izobreteniy, 1959, Nr 23, pp 85

An improvement in the above pump, this paper is distinguished by the synchronous closing of the inlet side of the control valve after the discharge has occurred within the pump's chamber. The time between repeated discharges is retarded to allow for fluid transit time and time for the control valve to re-position itself to the normally open position.

In dealing with shock waves of short duration, the use of a fast acting valve to prevent "backlash" of the fluid into the supply line becomes important.

"SPECIALIZED HORIZONTAL HYDRAULIC PRESS" (1958)
Kuz'ko, Yu. P. et al (5)
Patent Class 58a, 1. No. 119073 (468216) April 8, 1958

This very brief, but pertinent article relates the development of a specialized press capable of 100,000 tons of force. The extrusion of thick walled pipes into thin walled pipes containing internal "T" like ribs is accomplished through the use of electrohydraulic spark discharge techniques. The tubular billet is preheated to reduce its resistance to deformation prior to being ejected by a force acting on a ram subjected to a hydrostatic pressure. The extrusion process starts with the aid of multiple shock pulses acting on the ram through the compressed fluid.

As this article relates directly to extrusion by capacitor discharge techniques, the patent is reproduced in full on the following page.

"Special Horizontal Hydraulic Press" (1958) Patent No. 119073
Kuz'ko, Yu. P. et al

The invention relates to a specialized hydraulic press capable of forces up to 100,000 tons, designed for the pressing of tubes or pipes with internal lengthwise ribs.

The known universal hydraulic presses are very bulky and heavy; in addition, it is difficult to adapt them for the pressing of such tubes. The distinctive feature of this invention is its structural design which takes the form of a container consisting of lengthwise cross-sectional squared beams that take up the axial loading. Radial loading is taken up by the use of multi-layers of firm banding placed over the entire assembly. The use of hydraulic cylinders serving as intensifiers by virtue of their use as spark discharge chambers, are located in the butt ends of the cross-sectional squared beams.

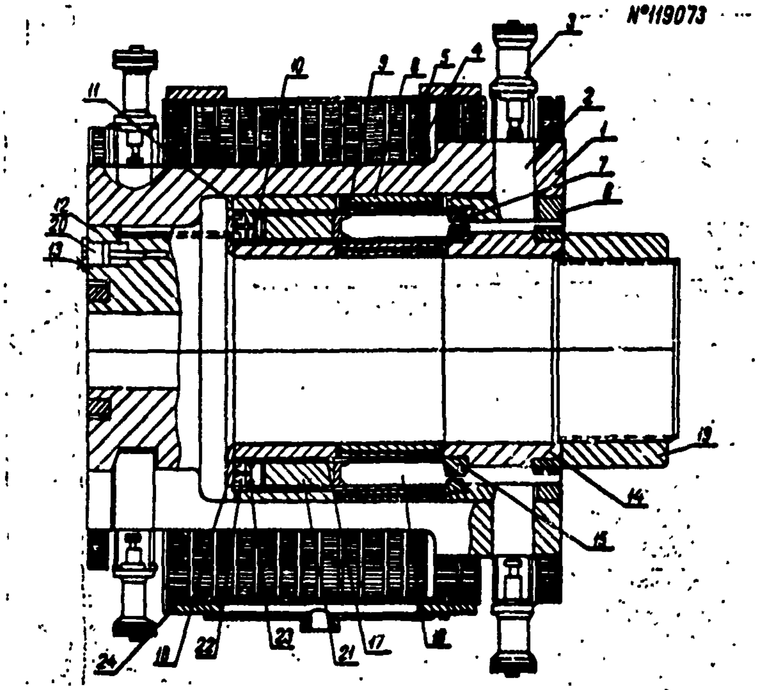
This type of press construction reduced its size and weight. The sketch shows the general appearance of the press in the lengthwise cut.

The container consists of lengthwise cross-sectional square beams (1) in which are fastened wedge-shaped keys (2), taking up the axial load and are activated by hydraulic cylinders (3). Placed over (1) are the multi-layered reels of firm banding (4) taking up the radial load. The banding is encased in a thin-walled metallic housing (5).

In the container is mounted a ring type die mandrel (6) containing O. D. die (7) and internal rings (8) that house heater coils (9). To provide a hydraulic seal for the internal cavity of the container, a thin-walled cylinder (10) is firmly secured at its butt end to a washer (11).

The ram of the press which forms the internal contour of the thin-walled cylinder consists of four lengthwise squared beams (12), tightened with external rings (13). On the ram is fastened a hoop type die holder (14) with rib die (15). The O. D. die and rib die form the figured clearance through which the billet (16) is pressed through. In order to seal the ring type cavity of the container, the thin-walled cylinder (17) is set on the ram and is secured to gasket (18) located at the cylinder's butt end. The die holder and rib die are secured to the ram by a nut (19). The pressure originates in the spark discharge chambers (20) which are located at the rear of the press. From the discharge chambers, the high pressure liquid is introduced into the internal cavity of the container and acts on the ram (21) through an assembly (22) consisting of a collection of stamped thin steel and copper leaves tightened with bolts. Contained in the body of the ram is a valve (23) which permits the high pressure liquid to enter the cylinder during the spark discharge.

The press is mounted by means of supports (24) that are sunk into a concrete foundation.



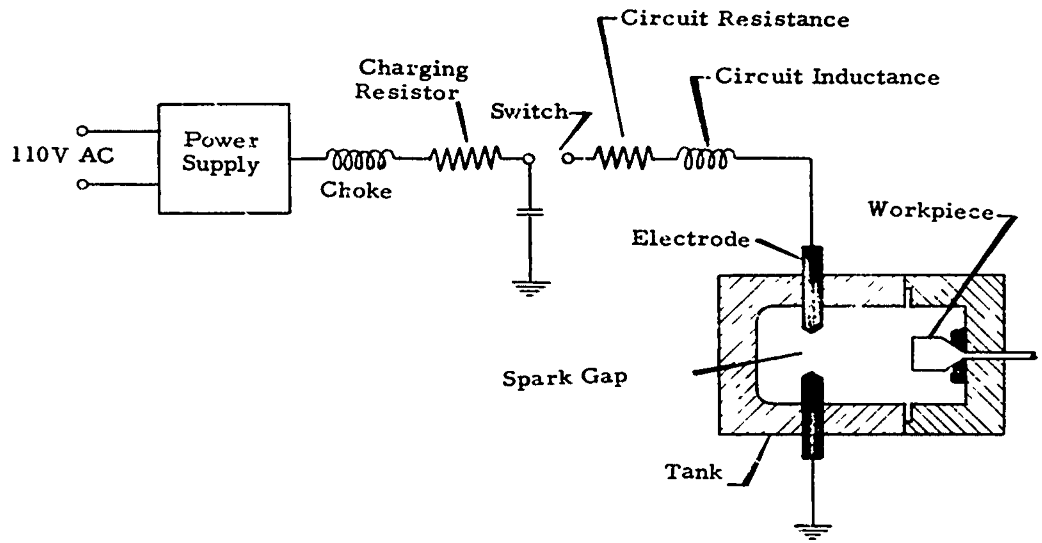
SKETCH OF "HORIZONTAL HYDRAULIC PRESS"
IN THE LENGTHWISE CUT

1. Lengthwise cross-sectional square beams. 2. Wedge-shaped keys. 3. Hydraulic cylinders. 4. Multi-layered banding. 5. Metallic housing. 6. Die mandrel. 7. O. D. Die. 8. Internal rings. 9. Heater Coils. 10. Cylinder. 11. Washer. 12. Lengthwise squared beams. 13. External rings. 14. Hoop type die holder. 15. Rib die. 16. Tubular billet. 17. Thin walled cylinder. 18. Gasket. 19. Nut. 20. Spark discharge chamber. 21. Ram. 22. Thin steel and copper leaves. 23. Valve. 24. Supports.

<u>The Object of Invention</u>

1. A specialized horizontal hydraulic press with a force of 100,000 tons for the extruding of tubes with internal lengthwise "T" shaped ribs containing a hydraulic drive mechanism in the form of discharge chambers in which the hydraulic fluid is subjected to repeated spark discharges for the generation of pressures necessary for the extruding process. In an effort to reduce the overall size and weight of the press, the body is made in the form of a container consisting of lengthwise cross-sectional square beams designed to take axial loading and the use of banding placed over the assembly designed to take the radial loading.

2. The press construction as mentioned in the description contained herein is different in that the spark discharge chambers are an integral part of the butt ends of the cross-sectional square beams due to container geometry.



TYPICAL CIRCUIT

ENERGY TRANSFER PHENOMENA FROM THE CAPACITOR DISCHARGE EVENT

Because the capacitor discharge phenomena as applied to metals fabrication procedures is a most recent innovation, it is appropriate to describe the capacitor discharge event and the consequences of the explosion created by a rapid discharge of the stored electrical energy across a gap as it will be put to use on this experimental extrusion program.

It is necessary that electrohydraulic extrusion be accomplished by the rapid release of energy stored in a high voltage capacitor bank between electrodes in appropriate liquid medium. After the storage of electrical energy in the capacitor bank is completed, the discharge event begins when the trigger switch (vacuum gap) is ionized and current flows in the circuit, thereby ionizing the gap between electrodes (refer to Figure 1). A spark channel is abruptly created and the vapor products in the channel expand in a spherical "gas bubble." The sudden creation and the initial high velocity bubble expansion produce a compression of the surrounding liquid. This compressed water layer then travels through the liquid as a pressure wave with approximately accoustic velocity. The wave endures for approximately 150 microseconds and contains up to 25% of the originally stored energy. The amount of energy extractable directly from the wave as deformation work in a workpiece or to be considered for transfer to the workpiece by mechanical means is dependent upon the distance of the electrode from the workpiece, the area portion of the pressure wave impinging on the workpiece surface, and the proportion of the pressure wave energy which is available for work. The kinetic energy of this liquid which is moving radially is a second source of energy which is also capable of producing work. The kinetic energy of the fluid surrounding the expanding gas bubble has been calibrated from experimental data at Republic Aviation Corporation to be as high as 15% of the total energy available. Thus, when added to the pressure wave energy, the total discharge energy convertible to mechanical form approaches 40% although it has been found that values in practical operation may range from 2 to 10%.

EXTRUSION EQUIPMENT DESIGN CONSIDERATIONS

1. Basic Vessel Design

(a) General

Because of the requirement to contain the large dynamic forces created by electrical energy spark gap discharges superimposed on high hydrostatic pressures, the problems involved with the design and development of extrusion equipment to reach the proposed objectives of this program are known to be complex and unique. Before fabrication of an appropriate chamber can commence, an analysis of the interaction of the static and dynamic loadings in the capacitor discharge extrusion container must be completed with a demonstrated assurance that the equipment produced will be adequate to contain the combined dynamic and hydrostatic loadings and to produce an extrusion. For this reason, the following criteria have been established as boundary conditions to attain the objectives of the program.

Working Cavity - 2 1/4 inside diameter x 26" working length
Hydrostatic Pressure - 200, 000 psi maximum
Dynamic Pressure - 425, 000 psi for 20 u sec peak duration
Hydraulic Flow Rate - 20 in^3 per minute at 200, 000 psi
Capacitor Discharge - Vessel to incorporate 1/2" diameter electrodes and accommodate discharges of 155, 000 joules (960 uf capacitance at 18 kv)
Accessibility - Vessel to be double ended. One closure shall contain the extrusion die and shall be accessible for examination and replacement of the die. The other closure shall contain the electrode and pressure port and shall be accessible for examination and replacement of the electrode. Provision for adjustment of the electrode gap must be made.

(b) Electrode

A problem of equal complexity to the dynamic design considerations is that of insulating and sealing the electrode in the chamber area. The

requirements are extremely stringent. The insulation must have the capability of providing a seal with the 200, 000 psi hydrostatic pressure imposed upon it. Furthermore, the electrode must accommodate the shock from a 155, 000 joule energy explosion and hold off a potential of 18, 000 volts. A study of the many reported techniques (1, 2, 3) for the introduction of electrical leads into a pressure vessel reveals that the methods used are for low voltage leads of small diameter wire where the problems are not so severe. However, the necessity for an electrode diameter of the order of 1/2" diameter and the requirement for it to carry the pressure port coupled with the limitations in size of the working cavity indicate development work will be required to obtain a working design.

(c) Hydraulic Cylinder Adapter

In the event the problems outlined in the previous sections prove to be insurmountable, a more versatile piece of equipment will be required. For this reason, a low pressure hydraulic cylinder adapter is to be included in the tooling arrangement. The adapter is to be made interchangeable with the closure of the high pressure chamber and is to include a piston-type ram extending with appropriate seals into the high pressure chamber. With this arrangement, a mechanical application of the energy derived from capacitor discharges may be made to the extrusion billet.

A further significant advantage of this arrangement is that the electrodes are moved out of the high pressure area. The lower pressure in the adapter does not present so severe a problem in sealing and insulating the electrode. Work in the past reporting period indicates that electrode sealing can be maintained with polyvinyl chloride insulation with static pressures to 6, 000 psi and spark discharge conditions to the 110, 000 joule energy level.

2. Dynamic Stress Considerations

Metals may be subjected momentarily to stresses exceeding their static yield stress without suffering plastic strain. This phenomena becomes significant when applied to the hardware design requirements of this program; i.e., a 425, 000 psi pulse pressure of 20 micro second duration superimposed in a maximum static pressure of 200, 000 psi. Before the vessel design can be

completed, it is essential to put the hypothesis to the test of analysis in order to find:

(1) The time a dynamic stress can exceed the static yield stress without suffering plastic strain.

(2) The magnitude of the dynamic stress that can be tolerated without plastic strain.

(3) The effect of plastic strain on the chamber if conditions (1) and (2) must be exceeded by pressure-time parameters dictated for the extrusion process.

Early in the reporting period, an intensive literature search into the behavior of metal under impulsive loads was instigated. Although some qualitative information was revealed, further study indicated that specific information relating material properties is sparse and cannot be related directly to the problem at hand. In addition, a precise understanding of metal behavior under shock loading is not yet available. Current studies are primarily concerned with testing specific materials under restricted conditions and hypothesizing as to the effects of strain-rate, grain size, etc. upon the elastic modulus and yield strength. Since additional general information in this field may be of interest, we note several survey works (4, 5, 6) each of which contain many references to further efforts with impulsive loading.

Two cases for a chamber undergoing shock-wave impulsive loading have been formulated and are being investigated. The first, based on the literature, (7, 8) indicates that the dynamic elastic limit for steel may be as high as four times its static counterpart. The second takes into consideration the fact that a time-history of stresses and strain (elastic and plastic) is afforded at each point in the pressure chamber wall by solving the wave equations by the method of characteristics. A bilinear stress-strain curve is used and the wave is assumed to by cylindrical.

The analyses are nearing completion and will be presented in their entirety at the conclusion of the next reporting period.

STATUS OF THE WORK

A State-of-the-Art survey in the field of shock-wave propagation and the effects produced by high energy discharges in materials has been completed. The two cases (elastic and elastic plastic) based on information revealed in the survey consider the effects on a chamber of shock wave impulsive loading superposed over a high hydrostatic pressure. Analysis results are being applied to pressure vessel design requirements. This work will be completed in the next reporting period.

A procurement specification for the pressure chamber and supporting ultra-high pressure pumping equipment has been determined. These criteria have been included as part of a Request for Proposal released by the Republic Aviation Purchasing Department midway in this reporting period. A number of interested bidders have been orally briefed by Republic Aviation personnel.

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Grafton Plant
Worcester Street
North Grafton, Massachusetts

Stauffer Metals Company
1201 South 47th Street
Richmond, California

United States Steel Corporation
Products Development Division
525 William Penn Place
Pittsburgh, Pennsylvania

U.S. Atomic Energy Commission
Technical Information Services Extension
Attn: Mr. Hugh Voress
P.O. Box 62
Oak Ridge, Tennessee

Wah Chang Corporation
Attn: Mabel E. Russell, Librarian
P.O. Box 366
Albany, Oregon

Wah Chang Corporation
Attn: Mr. K.C. Li, Jr.
100 Church Street
New York 7, New York

Wolverine Tube
Division of Calumet & Hecla, Inc.
Attn: Mr. F.C. Eddens, Manager
Special Metals, New Products Division
17200 Southfield Road
Allen Park, Michigan

IIT Research Institute
Metals Research Department
Attn: Mr. Frank A. Crosely
3350 South Federal Street
Chicago 16, Illinois

National Academy of Science
National Research Council
Div. of Engineering & Industrial Resources
Attn: Mr. E. V. Bennett
Washington 25, D.C.

NORAIR Division
Northrop Corporation
Attn: Mr. J. A. Van Hammersveld
1001 East Broadway
Hawthorne, California

Nuclear Metals, Inc.
Attn: Mr. Klein, Vice President
West Concord, Massachusetts

North American Aviation, Inc.
Attn: Plant Engineering Library
43 East Fifth Avenue
Columbus 16, Ohio

Oregon Metallurgical Corp.
Attn: Mr. Frank Vandenburgh
Vice President
P.O. Box 484
Albany, Oregon

Pressure Technology Corp. of Amer.
Attn: Mr. Alfred Bcorowski, Pres.
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Woodbridge, New Jersey 07095

Republic Aviation Corporation
Attn: Mr. A. Kastelowitz
Director Manufacturing Research
Farmingdale, L.I., N.Y.

Reynolds Metals Company
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Washington 6, D.C.

Lombard Corporation
Youngstown, Ohio

P.R. Mallory & Company, Inc.
Attn: Mr. A.S. Doty, Director
Technical Services Laboratories
Indianapolis 6, Indiana

Curtiss-Wright Corporation
Metals Processing Division
Attn: Mr. A.D. Roubloff
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National Aeronautics & Space Admin.
Lewis Research Center
Attn: Mr. George Mandal, Chief, Library
21000 Brookpark Road
Cleveland 25, Ohio

North American Aviation, Inc.
Attn: Mr. Walter Rhineschild
International Airport
Los Angeles 9, California

Oak Ridge National Laboratory
Metals & Ceramics Division
Attn: Mr. C. W. Thurber
P.O. Box X
Oak Ridge, Tennessee

Reactive Metals Products
Attn: Mr. G. W. Cleveland
Sales Engineer
Niles, Ohio

Republic Steel Corporation
Research Center
Attn: Mr. R. W. Kollar
6801 Breckville Road
Cleveland 31, Ohio

Union Carbide Nuclear Company
Attn: Mr. Paul E. Wilkinson
P.O. Box Y
Oak Ridge, Tennessee

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Literature survey in capacitor discharge extrusion and dynamic effects of shock loading have been completed. A stress analysis considering the effect of explosive shock type loadings is nearing completion. The objective of the program is to extrude steel to 1/4" rounds by the use of capacitor discharge energy. Pressure chamber requirements are that vessel must hold hydrostatic pressure of 200, 000 psi and be capable of containing shock energy from a 155. 000 joule capacitor discharge.

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